Effect of Extrusion on Hypocholesterolemic Properties of Rice, Oat, Corn, and Wheat Bran Diets in Hamsters

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ABSTRACT

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Brans from rice, oats, corn, and wheat were cooked in a twin-screw extruder at either high or low energy input, and their cholesterol-lowering effects were compared with those of unprocessed brans when fed to four-week-old male golden Syrian hamsters (*n* = 10 per treatment) for three weeks. Peanut oil was added to oat, corn, and wheat bran during the extrusion process to match the oil content of rice bran. Diets contained 10% total dietary fiber, 10.3% fat, 3% nitrogen, and 0.3% cholesterol. Plasma and liver cholesterol and total liver lipids were significantly lower with low-energy extruded wheat bran compared with unprocessed wheat bran. Extrusion did not alter the hypocholesterolemic effects of rice, oat, or corn brans. Plasma and liver cholesterol levels with corn bran were similar to those with oat bran. Relative cholesterol-lowering effects of the brans, determined with pooled (extruded and unextruded) bran data, were rice bran > oat bran > corn bran > wheat bran. Rice bran diets resulted in significantly lower levels of total plasma cholesterol and very low density lipoprotein cholesterol compared with all other brans. Total liver cholesterol and liver cholesterol concentrations (mg/g) were significantly lower with high-energy extruded rice bran compared with the cellulose control group. Plasma cholesterol and total liver cholesterol values with low-energy extruded wheat bran were similar to those with rice bran (unextruded or extruded) diets. Lowered cholesterol with rice bran diets may result in part from greater lipid and sterol excretion with these diets. Results with low-energy extruded wheat bran suggest that this type of processing may improve the potential for lowering cholesterol with wheat bran products.

Lowering cholesterol with cereals such as oat bran and rice bran has been reported extensively and was recently reviewed by Kahlon and Chow (1997). Postprandial lipemia was lowered with wheat fiber in a study by Cara et al (1992), while many other studies with wheat bran have not shown cholesterol-lowering effects. Instead, wheat bran has been used as a control treatment against which cholesterol-lowering effects of other cereals have been evaluated (Tredger et al 1991, Uusitupa et al 1992, Whyte et al 1992, Jackson and Topping 1993, Illman et al 1993, Rouanet et al 1993, Anderson et al 1994, Lewis et al 1996). Studies with corn bran have shown some lowering of total cholesterol and very low density lipoprotein (VLDL) cholesterol (Shane and Walker 1995), and other studies have shown no effect (Anderson et al 1994).

Many popular foods of cereal origin (e.g., ready-to-eat cereals, snacks, and pasta) are produced by extrusion processing. Extrusion results in a product with physical and chemical characteristics different from those of the original food (Harper 1979, Linko 1981). These differences depend on the extrusion parameters (e.g., time, energy, and the type of extruder used) and the physical and chemical properties (moisture, fat, and fiber content) of the raw material. Extrusion alters the starch, protein, fat, and fiber components of cereals, forming complexes that may affect their cholesterol-lowering properties. This study was conducted to evaluate four cereal brans (rice, oat, corn, and wheat) for the possible enhancement of their cholesterol-lowering potential by twin-screw extrusion at two energy levels.

MATERIALS AND METHODS

Male, 22-day-old weanling golden Syrian hamsters (Sasco, Omaha, NE) were housed individually in wire-bottomed cages in a controlled environment (20–22°C, 60% rh, 12-hr light and dark cycle) and fed ad libitum a basal diet (control diet minus cholesterol) for one week. Animals were then weighed and assigned to one of 13 treatments by selective randomization (blocked by weight, one animal per treatment from each block, 10 animals per treatment). Total feed consumption was measured, fresh feed was provided twice weekly, and animals were weighed once a week during the 21-day feeding period. All the procedures described were approved by the Animal Care and Use Committee of the Western Regional Research Center, USDA, Albany, CA, and conformed to the principles specified by the Committee on Care and Use of Laboratory Animals (1985).

Extrusion Conditions

Brans were extruded at maximum net torque (high net specific energy) in a corotating twin-screw extruder (Werner and Pfleiderer, Ramsey, NJ) and at 50% of the maximum level (low net specific energy). The empty extruder required 19% torque at 400 rpm. High torque level was determined by extruding rice bran samples containing 23.7% fat. Stable high net torque of 0.442 kWhr/kg (dry basis) was reached at 400 rpm and a feed rate of 19.5 kg/hr at a die temperature of 130–139°C. For high-torque extrusion, peanut oil was added (at feed ports 120 mm from the feed end of the screw) to oat, corn, and wheat brans to keep the fat level constant and at the same level as that of rice bran (23.7%) and to maintain fluidity. Peanut oil was chosen because its fatty acid composition is similar to that of rice bran oil and to distinguish the effects of the other brans from rice bran. For low-torque extrusion (0.221 kWhr/kg, dry basis), water was also added at the feed port to rice, oat, corn, and wheat bran at 5.24, 3.92, 14.53, and 9.05 kg/hr, respectively, to reduce the torque.

The screw configuration used for extrusion was as follows: RHSE, 40 PD × 150 (right-handed screw element, 40 mm pitch diameter × 150 mm long); RHSE, 26 PD × 60; RHKB × 40 (right-handed kneading block × 40 mm long); RHSE, 26 PD × 40; LHKB × 40 (left-handed kneading block × 40 mm long); RHSE, 26 PD × 40; RHKB × 40; SP × 1 (spacer × 1 mm long); LHKB × 40; RHSE, 26 PD × 40; RHKB × 40; SP × 1; LHKB × 40; RHSE, 26 PD × 60; LHKB × 40; SP × 1; RHKB × 40; SP X1; LHKB × 40; RHSE, 26 PD × 60; RHKB × 40; SP × 1; LHKB × 20; SP × 1; LHKB × 20; SP × 1; RHKB × 20; SP × 1; LHKB × 20; RHSE, 26 PD × 60; {RHSE × 10; SP × 1; LHSE × 10; SP × 1} × 5; RHSE, 26PD × 100; {RHSE × 10; SP × 1; LHSE × 10; SP × 1} × 8; RHSE, 40 PD × 100; END.

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Treatment diets (Table I) were formulated to contain 10% total dietary fiber (TDF), 10.3% fat, 3% nitrogen, and 0.3% cholesterol. The control diet (C) contained 10% cellulose and 10.3% peanut oil. All other diets contained bran from either rice, oats, corn, or wheat (obtained from local mills). Raw and extruded brans were analyzed for insoluble and soluble dietary fiber (Prosky et al 1988), nitrogen (Kjeldahl method), and moisture (dried overnight at 105°C). All diets were ether-extracted for crude fat by Method 920.39C (AOAC 1990), and their total sterol content was determined by the cholesterol assay procedure used for liver cholesterol. Composition of the raw and extruded brans is given in Table II. Treatment diets were formulated with the unextruded (U), low-energy extruded (L), and high-energy extruded (H) forms of rice bran (RB), oat bran (OB), corn bran (CB), and wheat bran (WB) for a total of 12 bran treatments. When necessary, dietary fat and protein N were equalized in the diets with peanut oil and casein, respectively.

After two weeks of feeding the treatment diets, total feces were collected for four consecutive days and analyzed for dry matter at 50°C under vacuum for 24 hr by Method 934.01 (AOAC 1990). Fecal samples were analyzed for crude fat by Method 920.39C (AOAC 1990), and the lipid was redissolved in chloroform and methanol, 86:14, for determination of total neutral sterols. Aliquots (50 µL) were dried under nitrogen, solubilized with Triton X-100 (Carlson and Goldfarb 1977), and analyzed for total neutral sterols by the same enzymatic colorimetric procedure as that used for plasma cholesterol (PC).

At the end of the 21-day feeding period, all animals were fasted for 16 hr and anesthetized with CO_2 for tissue sample collection. Blood was drawn by cardiac puncture into plastic tubes containing anticoagulant (ethylenediamine tetraacetic acid and dipotassium salt, 0.8 mg/mL of blood) and centrifuged at 1,500 × g for 30 min at 4°C to obtain plasma. Livers were excised, rinsed, blotted, weighed, and kept on dry ice. Liver and plasma aliquots were stored at –70°C until analysis. Plasma samples were analyzed by an enzymatic colorimetric procedure for cholesterol (diagnostic kit no. 352, Sigma Chemicals, St. Louis, MO). PC values were determined with standard curves obtained by running several concentrations of standards provided with the respective kits.

Fresh plasma samples were pooled (two animals per pool) by using an equal volume of plasma from each animal. A protease inhibitor, epsilon-amino caproic acid (ICN Biomedicals, Costa Mesa, CA), 1.3 mg/mL of plasma, and an antimicrobial agent, garamycin 50 mg/mL (Schering, Kenilworth, NJ), 10 µL/mL of plasma, were added to stabilize the plasma. Lipoproteins were fractionated by density gradient ultracentrifugation (Havel et al 1955). After the background density of 1 mL of plasma was adjusted to 1.019 g/mL with 5 mL of NaCl solution (1.0214 g/mL), plasma was centrifuged in an ultracentrifuge (model L8, Beckman, Palo Alto, CA) at 40 K for 18 hr at 17°C in a rotor (model 50.3, Beckman). The top 1 mL (<1.019 g/mL) was removed as the VLDL fraction, and another 1 mL was removed as background. The subnatant density was adjusted to 1.067 g/mL and centrifuged similarly for 24 hr. The top 1 mL (1.019–1.063 g/mL) was removed as the low density lipoprotein

TABLE I
Composition of Diets (% dry matter)[a]

Diet	Fiber Source	Extrusion Level	Cellulose	Bran	Casein	Peanut Oil	Corn Starch	Dietary Fiber		Total Sterol (%)
								Insoluble	Soluble	
C	Cellulose	None	10	. . .	20.0	10.3	54.4	10.0	0.0	0.29
RBU	Rice bran	None	. . .	36.9	13.8	1.6	42.4	9.06	0.94	0.51
RBL	Rice bran	Low	. . .	39.6	13.6	1.6	39.9	9.10	0.90	0.60
RBH	Rice bran	High	. . .	35.8	13.9	1.6	43.4	9.00	1.00	0.50
OBU	Oat bran	None	. . .	51.4	10.0	6.4	26.9	7.43	2.57	0.33
OBL	Oat bran	Low	. . .	52.3	11.2	6.4	24.8	7.57	2.43	0.32
OBH	Oat bran	High	. . .	45.2	11.9	6.4	31.2	7.57	2.43	0.36
CBU	Corn bran	None	. . .	11.6	19.6	10.1	53.4	9.97	0.03	0.32
CBL	Corn bran	Low	. . .	13.8	19.7	10.1	51.1	9.92	0.08	0.33
CBH	Corn bran	High	. . .	14.0	19.7	10.1	50.9	9.95	0.05	0.34
WBU	Wheat bran	None	. . .	19.2	16.6	9.6	49.3	9.28	0.72	0.48
WBL	Wheat bran	Low	. . .	21.5	17.1	9.6	46.5	9.39	0.61	0.31
WBH	Wheat bran	High	. . .	22.5	16.7	9.6	45.9	9.30	0.70	0.42

[a] All diets contained mineral mix, 3.5%; vitamin mix, 1%; DL-methionine, 0.3%; choline bitartrate, 0.2%; and cholesterol, 0.3%; and were equal in total dietary fiber (10%), crude fat (10.3%), and N (3%).

TABLE II
Composition of Raw and Extruded Brans (% dry matter)[a]

Bran Source	Extrusion Level	Diet	TDF[b] (%)	IDF[c] (%)	SDF[d] (%)	SDF/IDF	Fat[e] (%)	Nitrogen (%)
Rice bran	None	RBU	27.0	24.5	2.5	0.102	23.7	2.5
Rice bran	Low	RBL	25.3	23.0	2.3	0.100	24.0	2.5
Rice bran	High	RBH	27.9	25.1	2.8	0.112	24.4	2.6
Oat bran	None	OBU	19.5	14.5	5.0	0.345	7.5	2.9
Oat bran	Low	OBL	19.1	14.5	4.6	0.317	18.7	2.6
Oat bran	High	OBH	22.1	16.7	5.4	0.323	22.8	2.7
Corn bran	None	CBU	86.5	86.3	0.2	0.002	1.4	0.5
Corn bran	Low	CBL	72.5	72.0	0.5	0.007	22.9	0.4
Corn bran	High	CBH	71.2	70.9	0.3	0.004	23.0	0.3
Wheat bran	None	WBU	52.2	48.4	3.8	0.079	3.8	2.7
Wheat bran	Low	WBL	46.5	43.7	2.8	0.064	24.8	2.0
Wheat bran	High	WBH	44.4	41.3	3.1	0.075	21.4	2.2

[a] Triplicate analyses.
[b] Total dietary fiber.
[c] Insoluble dietary fiber.
[d] Soluble dietary fiber.
[e] High fat content of extruded oat bran, corn bran, and wheat bran results from the peanut oil added during extrusion.

(LDL) fraction, and another 1 mL was removed as background. The subnatant contained the high density lipoprotein (HDL) fraction. With each ultracentrifugation, two salt solution tubes with similar density were run, and the densities of their fractions were monitored with a density meter (model DMA-48, Anton Paar, Richmond, VA). Lipoprotein fractions were analyzed for cholesterol by the procedure described for plasma.

Each liver was individually thawed, minced, and thoroughly mixed to obtain a homogeneous 0.3-g sample for extraction of total lipids by a supercritical fluid extraction procedure (Kahlon et al 1996b). Briefly, liver aliquots were mixed with pelletized diatomaceous earth adsorbent (Hydromatrix, Varian, Harbor City, CA) in 10-mL crystalline polymer cartridges (Isco, Lincoln, NE) and extracted with a combination of 72 mL of supercritical CO_2 (7,500 lb/in^2) and 28 mL of ethanol (10,000 lb/in^2) at a combined flow rate of 2.5 mL/min in a chamber maintained at 80°C. Ethanol was evaporated under nitrogen, and the lipid extract was dried in a 90°C oven for 45 min and stored at −17°C until dissolved in 10 mL of chloroform and methanol, 86:14, for cholesterol analysis. Liver total cholesterol was determined in aliquots (30 µL) of extract after evaporation under nitrogen and solubilization with Triton X-100 (Carlson and Goldfarb 1977); the enzymatic kit used was the same as that used with plasma. Values were determined from standard curves obtained by running National Bureau of Standards reference material for cholesterol (SRM 911b) through the procedure as described for the samples.

Statistical Analyses

Values were determined in triplicate, and analysis of variance and Duncan's new multiple range test (Steel and Torrie 1960) were conducted. A value of $P \leq 0.05$ was considered the criterion of significance.

RESULTS AND DISCUSSION

Extrusion Effects on Brans

Extrusion of rice bran at low energy and of corn and wheat brans at both low and high energy resulted in small decreases in TDF, whereas a small increase in TDF resulted with high-energy extrusion of oat bran (Table II). There were no major shifts in the ratio of soluble to insoluble fiber with extrusion in any of the brans. Wang and Klopfenstein (1993) found great variability in extrusion effects on dietary fiber in oat bran with hulls, barley with hulls, and whole wheat. Other investigators reported increases in soluble dietary fiber (SDF) when a variety of cereal grains and fractions were extruded (Bjorck et al 1984, Aoe et al 1989, Oda et al 1988, Ralet et al 1990, Siljestrom et al 1986, Shinnick et al 1988, Wang et al 1993). Differences in results could be related to differences in extrusion conditions, to the nature of the raw materials, and to the addition of peanut oil to the brans during extrusion (to keep the fat level equivalent to that of rice bran) in this study.

Weight Gain and Feed-to-Gain Ratio

Weights on arrival for 22-day-old male hamsters were 46.2 ± 0.6 g (mean ± standard error of the mean). After one week of basal diet, selectively randomized initial weights were similar for all treatments (66.7 ± 2.5 g). Although feed intake was similar among all treatment groups during the 21-day feeding period (9.0 ± 0.2 g/day), significantly higher weight gain and final weights were observed in hamsters fed the OBU diet compared with those fed C, RBL, RBH, CBU, CBH, and WBL diets (Table III). Apparent dry matter digestibility evaluated during days 14–17 was significantly higher for animals fed OBU, OBL, and OBH diets than for those in all other treatments, which may have contributed to the greater weight gain in the OBU group. The lowest dry matter digestibility values were observed with RBU or RBH diets; these values were significantly lower than those with CBL, CBH, and WBL diets in addition to all oat bran diets. Significantly lower feed-to-gain ratios were observed with OB (U, L, H) diets compared with cellulose control, RB (L, H), CB (U), or WB (L) diets. Extruded brans did not influence weight gain, final weight, feed-to-gain ratio, and apparent dry matter digestibility relative to unextruded brans, except the CBL diet, which was significantly more digestible than the CBU diet. The data suggest that the extrusion conditions used in this study improved the digestibility of corn bran but did not significantly alter the digestibility of rice, oat, or wheat brans.

Total PC

Total PC was not significantly influenced by any treatment compared with the cellulose control, except that WBU-fed animals had PC values significantly higher than those fed C, RB (U, L, H), OB (U, H), CBH, and WBL (Table IV). Elevated PC values with wheat bran have been reported (Tredger et al 1991, Uusitupa et al 1992, Whyte et al 1992, Jackson and Topping 1993, Illman et al 1993, Rouanet et al 1993, Anderson et al 1994, Lewis et al 1996). Hamsters fed WBL diet had significantly (12%) lower PC compared with those fed unextruded WB diet. Although PC values for the WBH diet group were 5% lower than those for the WBU group, they were statistically similar to those of the WBU and WBL groups. The data suggest that the hypercholesterolemic activity of wheat bran can be reduced or eliminated by low-energy extrusion. Extruding rice bran, oat bran, or corn bran at low or high energy levels did not significantly influence their hypocholesterolemic prop-

TABLE III
Effect of Raw and Extruded Rice, Oat, Corn, and Wheat Bran Diets on Weight Gain, Final Body Weight, Apparent Dry Matter Digestibility, and Feed-to-Gain Ratio in Hamsters[a–c]

Diet	Fiber Source	Extrusion Level	Weight Gain (g/21 days)	Final Weight (g)	Apparent Dry Matter Digestibility[d] (%)	Feed-to-Gain Ratio
C	Cellulose	None	48 ± 3b	115 ± 4b	85.8 ± 0.3b–e	4.1 ± 0.2ab
RBU	Rice bran	None	50 ± 2ab	117 ± 3ab	84.6 ± 0.6de	3.8 ± 0.1a–e
RBL	Rice bran	Low	46 ± 3b	113 ± 3b	85.7 ± 0.3b–e	4.2 ± 0.2a
RBH	Rice bran	High	46 ± 2b	112 ± 2b	84.0 ± 0.6e	4.1 ± 0.2ab
OBU	Oat bran	None	58 ± 4a	126 ± 5a	90.6 ± 0.3a	3.3 ± 0.2e
OBL	Oat bran	Low	55 ± 3ab	122 ± 3ab	91.7 ± 0.3a	3.4 ± 0.1de
OBH	Oat bran	High	53 ± 3ab	120 ± 3ab	90.1 ± 0.6a	3.5 ± 0.1c–e
CBU	Corn bran	None	46 ± 3b	113 ± 3b	85.5 ± 0.5c–e	4.1 ± 0.2ab
CBL	Corn bran	Low	50 ± 4ab	116 ± 3ab	87.3 ± 0.5b	4.0 ± 0.3a–c
CBH	Corn bran	High	48 ± 2b	113 ± 3b	86.5 ± 0.6bc	4.0 ± 0.1a–d
WBU	Wheat bran	None	55 ± 2ab	121 ± 3ab	86.0 ± 0.9b–d	3.6 ± 0.2b–e
WBL	Wheat bran	Low	46 ± 3b	113 ± 3b	87.3 ± 0.6b	4.2 ± 0.2ab
WBH	Wheat bran	High	53 ± 3ab	120 ± 3ab	86.3 ± 0.8b–d	3.6 ± 0.1b–e

[a] Mean ± standard error of the mean.
[b] Values followed by different letters within a column differ significantly ($P \leq 0.05$).
[c] Initial body weights and feed intake were similar among all treatments (67 ± 3 g and 9.0 ± 0.2 g/day, respectively).
[d] Based on feed intake and fecal excretion data for four days (days 14–17).

erties. Wang and Klopfenstein (1993) reported significant PC reductions in rats fed extruded oats (with hulls), wheat bran, and barley (with hulls) compared with their respective unextruded products. Other investigators have shown no significant influence of extrusion on the cholesterol-lowering effects of oat products in rat-feeding studies (Shinnick et al 1988, Oda 1988). The lack of PC reduction with 51.4% OB diet in this study may relate to the lower SDF-TDF ratio (0.26) of the oat bran. Previously we reported significant PC reductions with a similar oat bran diet in which the SDF-TDF ratio was 0.43 (Kahlon et al 1993). The SDF of oat bran has been reported to be responsible for its cholesterol-lowering properties.

VLDL, LDL, and HDL Cholesterol

VLDL cholesterol (VLDLc) values (mg/dL) for all bran diets were similar to values observed with the cellulose control diet; VLDLc values were not influenced by diets containing extruded versus nonextruded brans of the same cereal group (Table IV). However, VLDLc in hamsters fed RB (U, L) diets was significantly lower than in those fed CBL and WBU diets. VLDLc values with RBU diet were also significantly lower than with OB (L, H) and WBL diets.

LDL cholesterol (LDLc) values (mg/dL) were similar for all bran treatments compared with those of the cellulose control, except for groups WBU and WBH, in which values were significantly higher than those of the control group. LDLc (mg/dL) for animals fed WBL diet was 22% lower than that in hamsters fed WB (U or H); however, this difference was not significant because of the high within-treatment animal variability. Extruded brans did not significantly influence LDLc values compared with the corresponding unextruded bran of the same cereal.

HDL cholesterol (HDLc) values (mg/dL) in all treatment groups were similar to those of the C group; values were not significantly influenced by extrusion of any of the brans tested. In animals fed CBH diet, HDLc levels were significantly higher than in those fed OBL. Ratios of HDLc/(VLDLc + LDLc) were similar in all bran treatment groups compared with the control group; values were not significantly influenced by extrusion of any of the brans within each cereal group tested. The highest HDLc-to-nonHDLc ratio was observed in hamsters fed RBU diet and was significantly higher than in animals fed OB (L, H) and WB (U, H) diets. The higher HDLc-to-nonHDLc ratio may be considered beneficial in terms of a reduction in risk of atherosclerosis associated with a relative increase in HDLc (“good” cholesterol).

Liver Weight, Lipids, and Cholesterol

Liver weights per 100 g of fasting body weight were similar in all treatments compared with the control group, except for the weights of hamsters fed OB (L, H) diets, which were significantly higher than weights of the control group (Table V) and may be a reflection of greater weight gains with the oat bran diets. Liver weights were significantly lower in animals fed RBU diet compared with those fed OB (U, L, H) and WB (U, L, H) diets and in those fed RBH diet compared with those fed OB (U, L, H) and WBH diets. There was no significant influence of extruded versus nonextruded bran within the same cereal group on liver weight. Liver lipid per

TABLE IV
Effect of Raw and Extruded Rice, Oat, Corn, and Wheat Bran Diets on Plasma Cholesterol (PC), Very Low Density Lipoprotein Cholesterol (VLDLc), Low Density Lipoprotein Cholesterol (LDLc), and High Density Lipoprotein Cholesterol (HDLc) in Hamsters[a–c]

Diet	Fiber Source	Extrusion Level	PC (mg/dL)	VLDLc (mg/dL)	LDLc (mg/dL)	HDLc (mg/dL)	HDLc/ (VLDLc + LDLc)
C	Cellulose	None	352 ± 25bc	99 ± 8a–c	53 ± 6b	184 ± 6ab	1.24 ± 0.08ab
RBU	Rice bran	None	327 ± 11c	74 ± 11c	65 ± 6ab	188 ± 6ab	1.41 ± 0.16a
RBL	Rice bran	Low	341 ± 18bc	88 ± 14bc	68 ± 5ab	191 ± 9ab	1.27 ± 0.11ab
RBH	Rice bran	High	346 ± 12bc	95 ± 9a–c	75 ± 10ab	182 ± 9ab	1.15 ± 0.16ab
OBU	Oat bran	None	354 ± 13bc	100 ± 9a–c	71 ± 8ab	182 ± 5ab	1.10 ± 0.11ab
OBL	Oat bran	Low	371 ± 16a–c	126 ± 12ab	73 ± 8ab	169 ± 5b	0.88 ± 0.09b
OBH	Oat bran	High	358 ± 11bc	123 ± 9ab	67 ± 9ab	174 ± 10ab	0.95 ± 0.11b
CBU	Corn bran	None	366 ± 14a–c	103 ± 10a–c	71 ± 8ab	189 ± 16ab	1.14 ± 0.16ab
CBL	Corn bran	Low	381 ± 10ab	130 ± 4a	54 ± 2b	197 ± 6ab	1.07 ± 0.05ab
CBH	Corn bran	High	352 ± 17bc	97 ± 3a–c	64 ± 9ab	201 ± 11a	1.27 ± 0.10ab
WBU	Wheat bran	None	409 ± 15a	129 ± 17a	86 ± 14a	184 ± 6ab	0.86 ± 0.05b
WBL	Wheat bran	Low	361 ± 12bc	114 ± 25ab	67 ± 8ab	180 ± 12ab	1.08 ± 0.17ab
WBH	Wheat bran	High	388 ± 14ab	111 ± 7a–c	86 ± 15a	190 ± 8ab	1.01 ± 0.12b

[a] Mean ± standard error of the mean.
[b] Values followed by different letters within a column differ significantly ($P \leq 0.05$).
[c] $n = 5$, except for PC, where $n = 10$.

TABLE V
Effect of Raw and Extruded Rice, Oat, Corn, and Wheat Bran Diets on Liver Weight, Lipid, and Cholesterol in Hamsters[a–c]

Diet	Fiber Source	Extrusion Level	Liver Wt/100 g of Fasting Body Wt (g)	Lipid/100 g of Liver (g)	Cholesterol (mg/liver)	Cholesterol (mg/g of liver)
C	Cellulose	None	5.05 ± 0.07b–e	16.8 ± 0.6a	330.6 ± 8.3a–c	61.0 ± 2.3ab
RBU	Rice bran	None	4.86 ± 0.08e	13.4 ± 0.8cd	266.0 ± 20.2cd	49.9 ± 4.0b–e
RBL	Rice bran	Low	5.01 ± 0.12b–e	15.0 ± 0.3a–c	273.5 ± 12.8cd	51.7 ± 2.6b–e
RBH	Rice bran	High	4.97 ± 0.06de	13.7 ± 0.8cd	244.1 ± 22.4d	45.9 ± 4.0de
OBU	Oat bran	None	5.26 ± 0.09a–c	14.4 ± 0.6b–d	308.4 ± 25.4b–d	49.3 ± 3.5c–e
OBL	Oat bran	Low	5.34 ± 0.08a	14.3 ± 0.6b–d	271.1 ± 18.7cd	43.8 ± 2.7e
OBH	Oat bran	High	5.36 ± 0.07a	14.8 ± 0.6a–d	321.8 ± 19.6bc	53.5 ± 3.6b–e
CBU	Corn bran	None	5.04 ± 0.09b–e	14.3 ± 0.6b–d	311.9 ± 17.3bc	58.4 ± 2.6a–c
CBL	Corn bran	Low	5.05 ± 0.07b–e	14.6 ± 0.2b–d	310.2 ± 9.5bc	55.8 ± 1.0a–d
CBH	Corn bran	High	4.99 ± 0.08c–e	14.3 ± 0.5b–d	274.1 ± 14.3cd	51.5 ± 2.7b–e
WBU	Wheat bran	None	5.24 ± 0.09a–d	16.2 ± 0.3ab	352.6 ± 12.9ab	59.0 ± 2.0a–c
WBL	Wheat bran	Low	5.17 ± 0.12a–d	12.8 ± 1.2d	273.1 ± 39.1cd	48.8 ± 6.6c–e
WBH	Wheat bran	High	5.28 ± 0.08ab	16.2 ± 0.6ab	386.8 ± 19.0a	65.4 ± 3.3a

[a] Mean ± standard error of the mean.
[b] Values followed by different letters within a column differ significantly ($P \leq 0.05$).
[c] $n = 10$.

100 g of liver was significantly lower in hamsters fed all the bran diets, with the exception of RBL, OBH, WBU, and WBH, compared with those fed cellulose control diet. Liver lipid values in animals fed WBL diet were significantly lower than in those fed WBU or WBH diets, whereas liver lipid values were not influenced by extrusion in rice, oat, or corn bran diets. Total liver cholesterol in hamsters fed RBH diet was significantly lower than in those fed C, OBH, CB (U, L), and WB (U, H) diets. Animals fed WBL diet had significantly lower total liver cholesterol compared with those fed WB (U, H) diets. Total liver cholesterol or liver cholesterol concentration (mg/g) values were not significantly influenced by extrusion in rice, oat, and corn bran diets. Liver cholesterol concentration (mg/g) was significantly lower in animals fed RBH, OB (U, L), and WBL diets compared with those fed C and WBH diets. Liver cholesterol (mg/g) values for WB (L) were 17% lower than with WB (U), but this difference was not significant because of the high within-treatment variability. In rat studies, extruded grain diets (oats with hulls, wheat, and barley with hulls) reportedly resulted in significantly lower liver cholesterol compared with their respective raw grains (Wang and Klopfenstein 1993), while no consistent effect of extrusion was found by others (Shinnick et al 1988).

Mild extrusion conditions (0.232 kWhr/kg) of wheat bran have been shown to result in a marked increase in arabinoxylan and β-glucans, decreased protein solubility, and increased water absorption capacity (Ralet et al 1990). The decreased protein solubility and increased water absorption capacity were reversed with severe (0.386 kWhr/kg) extrusion conditions. This may have contributed to the reduced healthful response with high-energy (0.442 kWhr/ kg) extruded wheat bran in the present study. Significant PC and total liver cholesterol reductions with low-energy extruded wheat bran relative to unextruded wheat bran suggests an encouraging potential for the development of wheat products with more health-promoting properties.

Lipid and Sterol Excretion

During the four-day fecal-collection period (days 14–17), hamsters fed RB (U, L, H), OB (U, L), and WB (U, L, H) diets had significantly higher lipid excretion and significantly lower apparent lipid digestibility (digestibility = [intake − excretion]/intake) than those fed control diet (Table VI). In addition, lipid excretion for RB (U, L, H) diets was significantly higher and lipid digestibility significantly lower than in all other treatment groups, while values for lipid excretion in WB (L, H) groups were significantly higher and lipid digestibility significantly lower than those in the CB (L, H) groups. High-energy extrusion of oat bran resulted in significantly lower excretion and raised digestibility of lipids compared with unextruded oat bran, suggesting that high-energy extrusion may not improve the lipid-lowering properties of oat bran. Extrusion did not significantly influence lipid excretion or digestibility in RB, CB, and WB diets. Cholesterol intake was similar in all treatment groups compared with the control group, except the CBL group, whose cholesterol intake was significantly higher than that of the C, RB (U, H), OB (U, L, H), CBU, and WBH groups. Cholesterol intake of the RBL group was significantly higher than that of the RBH group. Higher cholesterol intake in the CBL and RBL groups resulted from higher feed intake in these groups during the four-day fecal-collection period. Sterol intake in animals fed RB (U, L, H), OB (U, H), CB (L, H), and WB (U, H) diets was significantly higher than in those fed C diet. Higher sterol intake with cereal diets compared with the cellulose diet is a reflection of the higher sterol content of the cereal diets (Table I). Variability of sterol intake within the cereal diets reflects feed-intake differences during the four-day fecal-collection period. RB (U, L, H) diets resulted in significantly higher sterol excretion compared with C, OB (U, L, H), CB (U, L, H), and WB (L, H) diets. This may be related to the higher sterol content of RB diets resulting from the high amount of unsaponifiable matter in the rice bran (Kahlon et al 1996a). Increased excretion of neutral sterols with RB diet has been previously reported (Kahlon et al 1996a).

Relative Cholesterolemic Response of Brans

Data were pooled for all treatments within each bran in order to compare the relative cholesterol-lowering properties of each bran, including both the raw and extruded forms. In hamsters fed RB or OB diets, PC was significantly lower than in those fed WB diet (Table VII). PC values of the RB group were also significantly lower than those of the OB and CB groups. Relative cholesterol levels for the bran diets were RB < OB < CB < WB. Significant cholesterol-lowering effects of RB and OB compared with WB diets were previously reported (Wang and Klopfenstein 1993, Whyte et al 1992, Rouanet et al 1993). We are not aware of any publications showing significant hypocholesterolemic effects of RB when compared with CB diets; however, Anderson et al (1994) reported an elevation in PC with RB diet relative to CB diet. The RB group had significantly lower VLDLc compared with the OB, CB, and WB groups. Shane and Walker (1995) observed some additional decreases in PC and VLDLc with CB and WB diets compared with decreases observed with a low-fat diet alone in hypercholesterolemic men. WB diet-fed animals had significantly higher LDLc

TABLE VI
Effect of Raw and Extruded Rice, Oat, Corn, and Wheat Bran Diets on Four-Day Lipid and Sterol Intake, Excretion, and Digestibility in Hamsters[a–c]

			Lipid				Sterol	
Diet	Fiber Source	Extrusion Level	Intake (g)	Excretion (g)	Digestibility[d] (%)	Cholesterol Intake (mg)	Intake (mg)	Excretion (mg)
C	Cellulose	None	3.85 ± 0.14bc	0.08 ± 0.01e	98.0 ± 0.1ab	112 ± 4bc	109 ± 4h	13 ± 2c
RBU	Rice bran	None	3.98 ± 0.10bc	0.34 ± 0.03a	91.5 ± 0.6g	116 ± 3bc	197 ± 5b	53 ± 13a
RBL	Rice bran	Low	4.22 ± 0.09ab	0.34 ± 0.01a	92.0 ± 0.1g	123 ± 3ab	248 ± 6a	39 ± 2ab
RBH	Rice bran	High	3.74 ± 0.13c	0.33 ± 0.02a	91.3 ± 0.5g	109 ± 4c	182 ± 7c	44 ± 7a
OBU	Oat bran	None	3.91 ± 0.16bc	0.20 ± 0.02b	94.7 ± 0.6f	114 ± 5bc	127 ± 5e–g	10 ± 2c
OBL	Oat bran	Low	3.95 ± 0.10bc	0.15 ± 0.02b–d	96.1 ± 0.6d–f	115 ± 3bc	122 ± 3f–h	9 ± 1c
OBH	Oat bran	High	3.68 ± 0.14c	0.13 ± 0.01c–e	96.5 ± 0.2b–e	107 ± 4c	129 ± 5e–g	8 ± 1c
CBU	Corn bran	None	3.67 ± 0.15c	0.09 ± 0.01de	97.5 ± 0.2a–d	107 ± 4c	115 ± 5gh	14 ± 2c
CBL	Corn bran	Low	4.39 ± 0.15a	0.09 ± 0.01de	98.1 ± 0.1a	128 ± 4a	140 ± 5e	17 ± 3c
CBH	Corn bran	High	4.09 ± 0.08a–c	0.09 ± 0.01de	97.8 ± 0.2a–c	119 ± 2a–c	137 ± 3ef	19 ± 3c
WBU	Wheat bran	None	4.03 ± 0.12a–c	0.15 ± 0.02b–d	96.3 ± 0.7c–e	118 ± 3a–c	189 ± 5bc	22 ± 10bc
WBL	Wheat bran	Low	4.06 ± 0.14a–c	0.17 ± 0.04bc	95.8 ± 0.8ef	118 ± 4a–c	123 ± 4f–h	20 ± 7c
WBH	Wheat bran	High	3.87 ± 0.16bc	0.16 ± 0.03bc	96.0 ± 0.7d–f	113 ± 5bc	157 ± 7d	18 ± 10c

[a] Mean ± standard error of the mean.
[b] Values followed by different letters differ significantly ($P \leq 0.05$).
[c] $n = 10$. Four-day feed-intake and total fecal-collection (days 14–17) data.
[d] [(Intake − excretion)/intake] × 100.

TABLE VII
Pooled Data of Extruded and Unextruded Rice, Oat, Corn, and Wheat Bran Diets for Comparison of Relative Effects of Each Bran on Plasma Total and Lipoprotein Cholesterol, Liver Lipid, and Liver Cholesterol in Hamsters[a–d]

					Liver	
Bran	PC (mg/dL)	VLDLc (mg/dL)	LDLc (mg/dL)	HDLc (mg/dL)	Cholesterol (mg)	Cholesterol (mg/g)
Rice bran	338 ± 8c	86 ± 7b	69 ± 4ab	187 ± 4ab	261 ± 11c	49 ± 2b
Oat bran	361 ± 8b	116 ± 6a	70 ± 5ab	175 ± 4b	300 ± 13b	49 ± 2b
Corn bran	366 ± 8ab	110 ± 5a	63 ± 4b	196 ± 6a	298 ± 8b	55 ± 1a
Wheat bran	386 ± 9a	118 ± 10a	80 ± 7a	185 ± 5ab	338 ± 17a	58 ± 3a

[a] Mean ± standard error of the mean.
[b] PC = plasma cholesterol; VLDLc = very low density lipoprotein cholesterol; LDLc = low density lipoprotein cholesterol, and HDLc = high density lipoprotein cholesterol.
[c] Values followed by different letters within a column differ significantly ($P \leq 0.05$).
[d] $n = 30$, except for VLDLc, LDLc, and HDLc, where $n = 15$.

compared with those fed CB diet. Pooled HDLc values with CB diets were significantly higher than HDLc values with OB diets. Total liver cholesterol values in RB, OB, and CB groups were significantly lower than those in the WB group. Values in the RB group were significantly lower than those in the OB and CB groups as well. Liver cholesterol concentrations (mg/g) were significantly lower in animals fed RB and OB diets compared with those fed CB or WB diets. Greater cholesterol reductions with RB may result in part from its oil content. Rice bran oil unsaponifiable matter has been reported to lower cholesterol relative to peanut oil in hamsters (Kahlon et al 1996a). Since the liver is the main cholesterol-synthesizing and cholesterol-catabolizing organ, significant liver cholesterol reductions by RB, OB, and CB diets in hamsters suggest that incorporating these brans into the diet would have great potential for alleviating or moderating hypercholesterolemia.

The results of this study show that extruding rice and oat bran does not alter their cholesterol-lowering properties and that cholesterol-lowering potential exists for corn bran as well. Extruding wheat bran at low energy resulted in significantly lower cholesterol levels compared with those of unextruded wheat bran, suggesting that extrusion of wheat bran under the appropriate conditions may enhance its potential to lower cholesterol.

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